1-1-2017

A New Centering Table For Encapsulated Glass Positioning

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A NEW CENTERING TABLE FOR ENCAPSULATED GLASS POSITIONING

by

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THESIS

Submitted to the Graduate School

of Wayne State University,

Detroit, Michigan

in partial fulfillment of the requirements

for the degree of

MASTER OF Engineering

2017

MAJOR:

Approved by:

__________________________7/31/2017

Advisor Date

ACKNOWLEDGEMENT

I would first express my appreciation to my thesis advisor Professor Wu in the Engineering Department at Wayne State University. Thank you very much for providing me the opportunity to conduct the research project in your lab. The door to Prof. Wu office was always open whenever I ran into troubles or had a question about my research or thesis writing. He always explained to me very carefully and patiently. He allowed me to serve on my own project and actively steered me in the right direction.

I would also thank the experts who were involved in the validation test for this research project: Encapsulation manager in an auto glass company-Sai Du. Thanks for his time and effort. Without their passionate participation and devotion, the validation of the research could not have been successfully conducted.

Finally, I must express my very special gratitude to my parents for providing me with unconditional support and continual encouragement throughout my learning career. During the long process of performing the research and writing this thesis, my parents encouraged and enlightened me to do the research work, especially when I encounter difficulties. This accomplishment would not be possible without you. Thank you.

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1 Introduction

1.1 Background of assembly line development

Larger production of cars: With the development of society, the demands of people on living quality are also increasing, especially in the last decades. People tend to look for a more efficient and comfortable lifestyle. The invention of cars really exerts a great impact on people's lives including changing the traveling methods, providing efficient and comfortable lifestyle, and boosting the development of the economy. Therefore, People began to depend more and more on cars since the invention of cars. With the development of technology, automobile industry experienced fast development and thus produced a lot of more advanced and cheaper cars, which made cars become available and helpful to a larger amount of people. According to the data collected by Statista: "Worldwide automobile production from 2000 to 2016." More than 72 million cars were manufactured all over the world in 2016 and the number of cars produced every year is still increasing, as shown in Figure 1 [1].

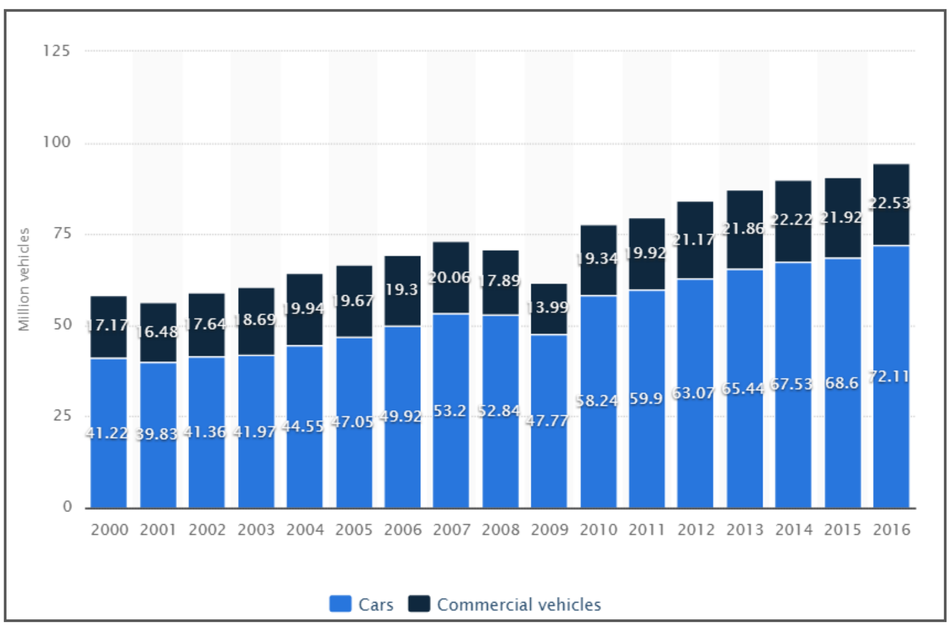

Figure 1 Worldwide automobile production from 2000 to 2016[1].

Huge demand on automotive glass: Most of car has quarter windows (also known as valence window), which is located at the front side window or the rear side window of the vehicle. The quarter window, which is usually made by encapsulated glass, is used to check the surrounding of the car [2]. The quarter windows are usually made by tempered glass encapsulated by chemicals such as thermoplastic elastomer (TPE), Polyvinyl Chloride (PVC), or polyurethane (PU) [3]. The fabrication process can be carried out as follows: first, chemicals were mixed to get the expected polymers; second, placing the raw glass into the injection mold (usually a steal or aluminum mold) with the border of the raw glass positioning exactly in a predetermined position in a mold cavity; third, close the mold and inject the polymer on the border of the glass through the frame mold to achieve encapsulation for the automotive glass [4].

Injection molding techniques: Several injection molding technologies are available in the field of automotive window encapsulation, such as rubber injection molding, reaction injection molding (RIM) with polyurethane systems, and thermoplastic injection molding with PVC/TPE-Compounds [5]. Among all the existing technologies, the thermoplastic injection molding process with PVC is the most prevailing technology due to its advantages for automotive glass encapsulation such as low material price, resistance to weather fluctuation, good visibility, and easy injection for the fabrication process [6]. Therefore, PVC encapsulated glass has been extensively used in quarter windows and sunroof device.

The adoption of encapsulated quarter window glass: Encapsulated quarter window (as shown in Figure 2) is widely adopted as automotive glass all over the world because encapsulated glass can provide various merits. (1), it is very stable and won’t do harm to people for any kind of chemical or physical reaction. Stability and nontoxicity are the fundamental requirements for any device used in people’s daily life, especially for encapsulated glass that is applied to cars. (2), it has a good sealing function, which can cancel noise and keep warm. The good sealing effect provides a good user experience for passengers in cars. (3), it is soft and thus serves as a buffer layer between the automotive glass and the car. This buffering effect plays an important role in the car capability of an external force, especially encountering some accidents, which can protect the passengers in the car [7].

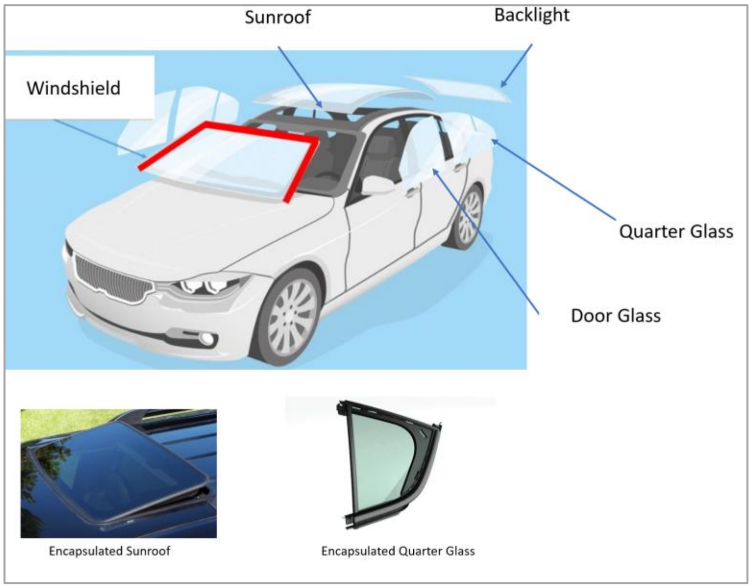

Figure 2 Schematic of the encapsulated quarter glass and a car.

The functions of polymer encapsulation: Polymer encapsulation is a very important procedure during the quarter window fabrication because it offers advantages during the fabrication process such as high efficiency, car fitting, easy fabrication, and high quality. At first, polymer encapsulation of glass can simplify the glass mounting process on the assembly line. Secondly, it has design flexibility and styling capabilities. Third, it can reduce the manufacturing cost by illuminating manual work. Fourth, the automatic processing can guarantee the high quality of encapsulated automotive glass [8].

Existing problems: Huge demand for cars results in the huge demand for encapsulated automotive glass [9]. For example, in 2016, More than 72 million cars were produced, and every car requires at least two pieces of automotive glass, leading to a demand of more than 144 million on the automotive glass in 2016.This huge demand for encapsulated automotive glass brings about the development of the encapsulated glass fabrication, which required efficient and low-cost manufacturing process. However, the fabricating cost is a major problem existing during the process of the encapsulated glass fabrication. Several factors can exert influence on the fabricating cost. At first, automotive glass with high quality is a fundamental requirement, which posted a challenge to the fabricating process. High-quality requirement usually results in a more complicated procedure and more time, which increases the cost of fabrication. Furthermore, the requirement of the fabrication is higher for the complicated glass shapes and inserted functional and aesthetic details of the glass. This requires additional process and effort, leading to higher labor force cost. Thirdly, the fabricating process has some strict standards to guarantee the perfect fitness and safety properties, also requires sophisticated equipment and additional fabrication procedures, and thus higher cost. At last, products are more customized and labor becomes more and more expensive.

Problems to solve: new technologies need to be developed and adopted to meet increasing demand of the market, reduce manufacturing cost, and maintain a high quality of the quarter window glass. In other words, a fully automated technique with a high precision of positioning is urgently needed for the fabrication of encapsulated automotive glass.

1.2 Introduction to automation line of encapsulated automotive glass

Automation line: also referred as an automated assembly line, consists of various workstations linked together and robot grabbing equipment, which facilitates to fabricate the encapsulated automotive glass efficiently and automatically with little or no workers involvement [10]. By adopting, the productivity of fabrication can be largely increased [11]. Moreover, automation line usually follows programming command and achieves greater precision and stable production. Furthermore, it is very easy to reconfigure the equipment depending on the needs of fabrication. At last, a large portion of the fabrication process is fulfilled by the connected mechanical equipment and automated systems. Workers can just focus on system adjustment, monitoring the fabrication process, and supervision, which can largely reduce the labor cost. Thus, automation line would be the best solution for the fabrication of encapsulated automotive glass.

The function of robots: Robots are used to quickly move and accurately position objects in the automated assembly line, which provides financial advantages and plays an important role in the fabrication process [12]. In glass encapsulation process, the robot grabs raw glass plate from the glass centering table and position glass plate into the mold, without any manual loading work. There is no human intervention during this process, eliminating the need for manual precise positioning. This robot grabbing process is quick and accurate for the fabrication of encapsulated glass, which can reduce half of the production cycle time than the fabrication without automation line. Moreover, adopting the robots on the assembly line can is very cost effective even in short production runs [13]. Among these processes, the glass centering table plays a significant role in this fabrication process.

The significance of a centering table: The function of the glass centering table is to maintain the glass plate exactly in the center of the table, making sure the glass always in an accurate position for each step. The key technique to ensure the stability of the glass centering table while still maintain the efficiency of operating the glass plate under the high density and frequency impact from the cylinder. With increasing requirement by the industry, glass centering station needs to sustain at least twice per minute higher intensity impact from tempered glass. Breakthroughs in this technology can largely boost the working efficiency of the automation line and thus increase the production of a factory and reduce the costs at the same time. In addition, an efficient centering table can also ensure the quality of the products, such as uniform and stable encapsulated glass [14]. Therefore, investigating the technology of centering table is worthwhile and very important for the development of this industry.

Encapsulation process: A traditional glass automation assembly process can be divided into three procedures including pre-processing, encapsulation, and post-processing, as shown in Figure 3(A). (1), Pre-processing. Glass or other related components should be placed onto the loading station by the operators. After the glass is centered by center station, the robot grabs the glass and follows the preset moving path, priming the glass at the primer station. (2), Encapsulation. After the glass is primed, glass needs to be centered again on the station before robot loads the glass onto the mold. Then glass was encapsulated by the polymer in the injection mold. (3), Post-processing. The robot removes the encapsulated glass out of the mold and places it into a conveyor. Operators or robots then take out encapsulated glass from the conveyor and install some components such as bright trim, foam, and 3M tape [15]. The schematic of the related automatic assembly line is shown in Figure 3(B).

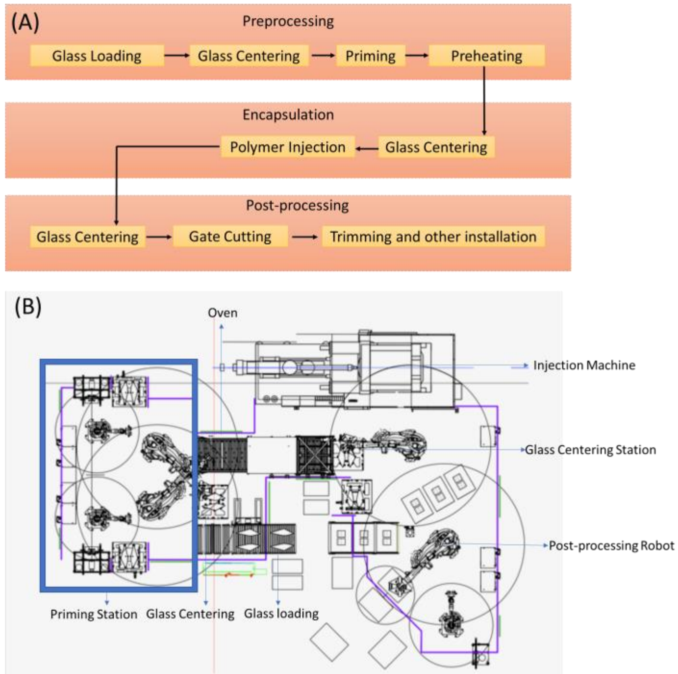

Figure 3 (A) Schematic of the traditional glass automation assembly procedure. (B) Schematic of a typical automatic assembly line.

1.3 The focus of this thesis

Existing problems in the current centering table: Currently, in the popular structure of a glass centering table, two M4 bolts are used to hold locators on the base pad. However, due to the property of bolt, the tightness between a bolt and a table relies on the small force of friction, leading to dislocation and poor precision. Moreover, though this existing structure is much easy to adjust for one type of quarter glass without too much dimension's difference, because the current has a straight slot shape adjusting area, it could be adjusted in any directions in horizontal. But the adjusting range is small. This kind of centering table cannot be used to produce various types of encapsulated glass and also fails to guarantee the precision and quality of the product, which cannot meet the requirement of the industry. In this thesis, detailed research will be carried out on the stability and adjustability of the centering table. A new design of centering table with novel column base structure will be developed.

The focus of this thesis: The thesis will focus on (1) Discuss the problems and disadvantages that exist in the current centering table, analyze the reasons for the existing problems. (2)Discuss the standard structure of glass centering table (3) Discuss selecting principles for selecting suitable air cylinders with matched parameters such as output force, operating speed, and air pressure. The load factors of the air cylinders will also be discussed to verify the compatibility of the air cylinders. (4) Finite element analysis will be carried out to discuss the force analysis of the glass on the centering table and verify that the current centering table cannot meet the need of industrial production. (5) Design pin holes and adopt both pins and bolts to tighten different components in the system, ensuring a more stable centering table and columns for positioning glass. This can improve the operating precision of centering table during to positioning process. (6) New column base will be designed. The new column base will adopt two components which are tightened by bolts and the distance of the two components can be adjusted by adding or removing shims with various widths. By adjusting the distance between two components of the column base, the positions of columns can be modified to fit other glass with different sizes and shapes. This can increase the flexibility of the new centering table as the designed centering table can be applied to other kinds of glass. (7) Fabricating results of glass using existing centering table and the newly designed centering table will be compared and discussed to verify the feasibility, productivity, and precision of the new designed centering table. (8) At the end, the thesis will conclude the advantages and disadvantages of the new centering table and show that this centering table can effectively boost efficiency while maintaining a high quality of the encapsulated glass as the designed table can effectively reduce the degree of freedom of the automotive glass.

2 Literature review

2.1 Introduction to the positioning mechanism.

With the increasing market demand and the development of the mechanical industry, automated assembly line plays an important role in the fabrication of the products such as automotive encapsulated glass. Among the techniques of the automated assembly line, the centering table is an essential and significant equipment for positioning products and thus increasing the efficiency and maintaining the high quality of the products. Therefore, a positioning system, especially a high precision positioning system plays a vital role in the research of automated assembly line [16].

Positioning mechanism refers to adjust the objects in the expected position for further processing by using mechanical components which are usually actuated by computer control systems [17]. The function of positioning in industrial production is to control and locate components fast and precisely, such as grasping and moving stuff to a specific position and ensuring the degree of freedom is controlled without any displacement and dislocation.

Mechanical positioning systems usually comprise hardware and software, which can be properly designed to be applied for automatic production. These mechanical positioning systems are quite flexible and can be adapted to other fabrication systems in the automated assembly line. Based on specific fabrication requirements, custom positioning components are assembled and coupled with the motoring components and the control system. For example, a Zaber`s computer-based positioning system adopts a stepper motoring component and precisely positions the object based on the received electrical signal.

The degree of freedom (DOF) in mechanical positioning systems refers to the minimum number of translation or rotation coordinates that are used to define the positions of the objects in the system [18]. For a rigid body, the DOF refers to the number of independent movements of the body. In other words, the DOF of a body can be defined as the ways it can be moved. For example, a rigid body in free space has 3 translating movements on the x axis, y axis, and z axis and 3 rotational movements around these axes, as shown in Figure 4. Therefore, this object has 6 degrees of freedom [19].

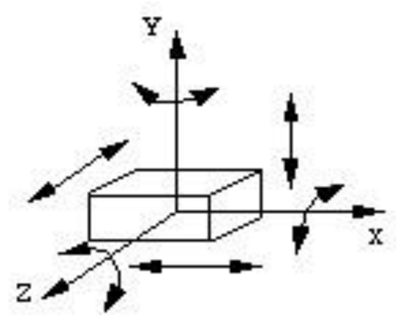

Figure 4 A rigid body in free space has 6 degrees of freedom [20].

While in a plane, the movement of the body will be constrained in two dimensions. Thus, the degree of freedom of the body is 3 in a plane. Specifically, the object can move in x axis (1 DOF), y axis (1DOF), and rotate on the x-y plane (1 DOF) [21], as shown in Figure 5.

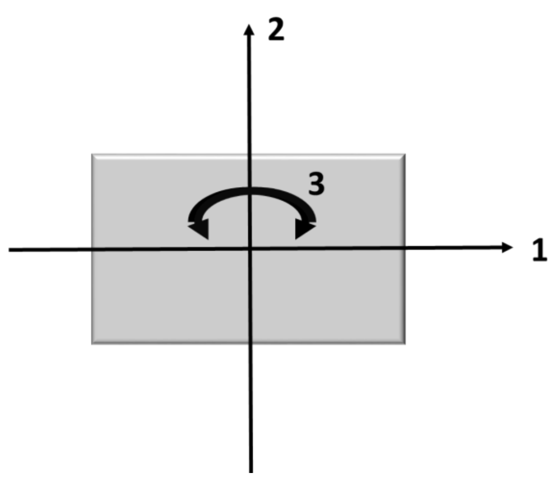

Figure 5 A rigid body in an x-y plane with 3 degrees of freedom.

A lot of methods can be used to constrain the movement and reduce the DOF of an object. This includes (1) Plane positioning, which mainly adopts supporting locations such as mounting plate and supporting nails to reduce the DOF of an object. (2) Cylindrical cam positioning, which uses centering positions and supporting positions to constrain objects. (3) Pin hole positioning, this utilizes positioning pins and mandrel to secure and support an object and reduces its DOF. (4) Conical positioning. The object was fixed by inserting a taper pin into the pin hole on the object. This can prevent the object moving in the direction along the pin except for other directions which can be constrained by a normal pin. Therefore, using conical bore positioning can constrain 5 DOF of an object except for the self-rotation of an object. This schematic diagrams of the four basic positioning mechanisms are shown in Figure 6.

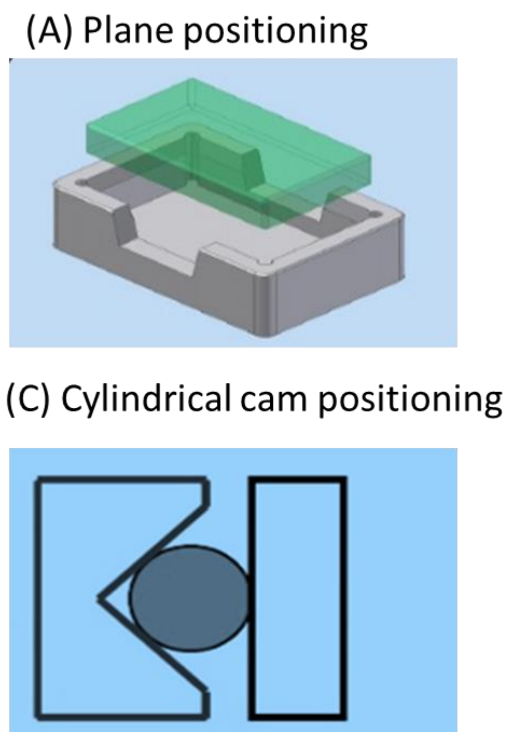

Figure 6 Schematic of the four basic positioning mechanism.

The automotive glass of this research is in a triangular prism shape, as shown in Figure 7.So plane positions method is an easier way for glass positioning. Three stands with the same height are needed on the centering table to support the glass, preventing the movement along the z-axis and any rotary motion on the x-z and y-z plane. During the centering process, the centering table should have the following constraints for the glass to remove the DOF of the glass and maintain the stability of the glass and the procession of the operation. This means one short-side column, two long-side columns are required to constrain the glass and prevent any movement along the y axis, x axis, and any rotary motion on the x-y plane. This can reduce the rest of 3 DOF of the glass.

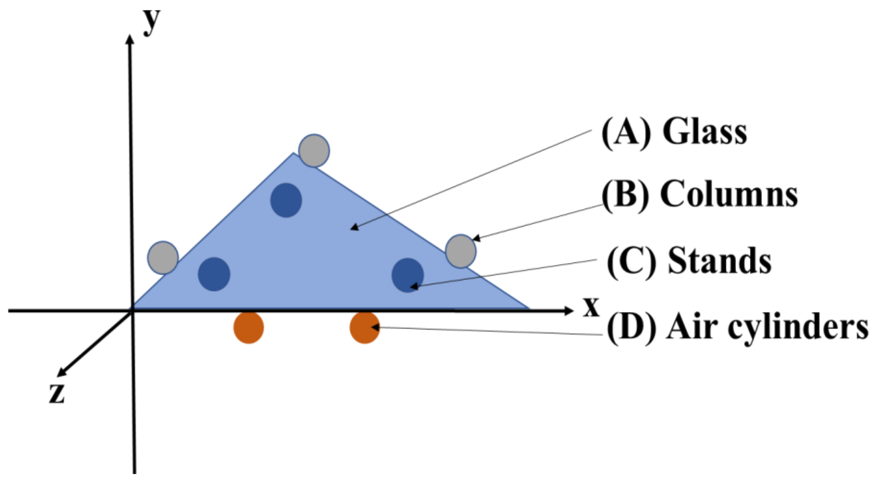

Figure 7 The columns and air cylinders needed on the centering table to constrain the glass and remove the DOF of the glass.

There are several noteworthy parameters in the mechanical positioning system (a centering table for encapsulated automotive glass), including the resolution, repeatability, accuracy, stability, etc. Resolution is the smallest incremental distance a mechanical positioning system can handle. Nowadays, mechanical positioning systems can reach a resolution of several micrometers and even on the scale of sub-micrometer. Accuracy refers to the maximum deviation of an object`s position from its real location to the expected position over the full moving distance. Stability refers to the ability of the system to keep an object at a position for a long period of time. All these parameters are important in evaluating the centering table as they will affect the efficiency, quality, and precision of production.

2.2 Previous investigations on tempered glass and automotive glass manufacture

Tempered glass or toughened glass, is a type of glass which is treated with high temperature (roughly 620 ˚C to 640 ˚C) after annealing and subsequent rapid quenching on the surface, which can significantly increase the mechanical strength of the tempered glass [22]. Tempered glass has a higher mechanical strength (4 to 5 times) than normal annealed glass without tempering. While the modulus of elasticity of tempered glass is not improved. In addition, tempered glass offers high resistance to temperature changes (up to 200K). The most important property of tempered glass is that it would break into small fragments without sharp edges when fracturing, which can reduce injury when the glass is broken [23, 24]. Therefore, tempered glass is also called safety glass, which makes it commonly used in side and rear windows of cars.

Tempered glass is an inorganic amorphous material. A glass sheet can build huge internal stress when it is heated up to a softening temperature and undergoes a cooling process. This kind of stress has uniform distribution inside the tempered glass, which results in a good impact resistance and heat stability [25]. The stress inside the tempered glass has a parabolic distribution. The tempered glass has a minimum stress value in the middle and has the maximum stress value at the edge or surface of the glass.

The toughening degree of tempered glass is affected by a lot of factors including temperature, cooling intensity, and the thickness of the glass. (1) Temperature. The toughening degree is a tempered glass is depended on the heating temperature. For a tempered glass with a certain thickness, the internal stress is proportional to the tempering temperature and cooling intensity, which means the toughening degree will be much higher under a high tempering temperature and a more rapid cooling process. (2) Cooling intensity, which means the speed of the cooling process. The speed of the cooling process is influential in the roughening degree of the tempered glass. For a sheet of glass with the same chemical composition and the same thickness, the toughening degree of the glass is depended on the speed of the cooling process for the glass tempered at the same temperature. A more rapid cooling process results in a higher toughening degree of the glass. (3) The thickness of the glass. The temperature gradient which results from the thickness of the glass can affect the internal stress of the glass. The temperature gradient during the cooling process is higher for a thicker glass sheet. Therefore, a thicker glass sheet has a higher toughening degree.

Littleton et al. introduced a method and apparatus for tempering glass to overcome the previous challenges such as moving the nozzle close to the surface of the sheet during tempering glass [26]. They provided a more efficient method for glass tempering and the method played an important role in fabricating tempered glass, which also boosted the development of the tempering glass industry. Barsom analyzed the fracture of thermally tempered glass and discussed the reasons that result in the fracture. Barsom summarized the mechanism and concluded that the fracture results from the elastic strain energy in the glass and the elastic energy release rate of the crack extension. This work is influential in the later research on tempered glass [27].

Lee et al. first proposed a theory to calculate the stresses result from glass tempering. Their model considered the viscoelastic properties of the glass which was tempered. This theory provided an important tool for researchers to study the property of tempered glass [28]. Narayana Swamy et al. evaluated this theory by comparing the experimental result with this proposed model and made some modification on this model [29]. Due to the structural heterogeneity of the tempered glass, the formulation in this study still could not explain the residual stresses when the glass was cooled from a lower starting temperature.

Generally, the variation of stress is nonlinear in most of the fragile materials such as glass and concrete. Due to the extension of micro-texture after damaged, the properties of these materials will be changed [30]. Therefore, we adopt elasticity-damage model to analyze the micromechanics of these materials. The elasticity-damage model not only considers the characteristics of fragile material damage but also considers the variation of the reminding stress after impact, which can be realized by simple numerical calculation. This elasticity-damage model has been applied to various fragile materials such as glass, rock, concrete, and brittle metal. After proposed by Dragon and Mroz, this model has been paid close extensive attention. Mazars developed a power function for this model and Loland introduced a nonlinear model for this model in the peak region [31].

There are three strength theories to analyze the fracture of materials. (1) Maximum tensile stress theory.

This theory believes that the maximum tensile on the material accounts for the damage, which means the material will have rupture failure when the tensile on the material reaches limit stress value [32]. (2) Maximum extension line strain theory. This theory believes that brittle rupture of the glass can result from the extension line strain exceeds an extreme value. (3) Deviator strain energy theory, which believes the variation of the shape can partially account for the damage [31]. As the tempered glass is a kind of fragile materials, the maximum tensile stress theory is suitable to analyze the fracture and damage of tempered glass.

Nielsen et al further studied Narayana Swamy's model and proposed a three-dimension investigation of the residual stresses in the tempered glass. This paper demonstrated the impact of glass thickness, distance to the hole, and interaction around holes on minimal residual compressive stresses [33]. The results demonstrate the relation between residual stresses and geometric features and offered a new tool to evaluate residual stresses in the tempered glass. Bernard et al. adopted a finite element approach to simulate the thermal tempering process and explore the residual stresses near edges of a glass. Bernard et al. simulated the heat transfer in the glass during the tempering process which determined the distribution of stresses and found that this heat transferring is influential to the thermal radiation and forced convection [34].

Aben introduced a new method to measure edge stress in the tempered glass. In the past, researchers adopted either light surface propagation method or scattered light method, both of which are costly. Aben verified that edge stress of tempered glass roughly equal to the value of surface stress, which provides a much easier approach to estimate stress distribution of tempered glass [35]. Schneider et al. explored the stress relaxation process in the tempered glass which is caused by heat soak testing. Numerical studies and experiments tests result confirmed that heat soak testing can influence the stress distribution [36]. Other parameters such as temperature, glass thickness, and activation energy were also investigated in order to thoroughly explore this phenomenon. This work is very important for understanding the factors which can affect the stress distribution in the tempered glass.

Due to the safety and high mechanical strength, tempered glass has been widely applied to automotive industry. Most of the automotive glass includes windshield, side and rear window utilize tempered glass. Large-scale production of tempered glass in the automation lines required a higher precision of the operational process. The tempered glass in the automation line experiences many operations such as centering, positioning, and transferring, which requires precisely controlling on the glass. Therefore, a lot of researchers focuses on the surface stress and the mechanical properties of tempered glass. Timmel et al. used a finite element model to simulate the impact on tempered glass [37]. The simulation focuses on laminated glass and explored the elasticity of the glass and the result after experiencing impacts. While this paper fails to provide a crash test of the laminated glass. Peng et al. adopted finite element modeling to study the mechanical behavior of automotive windshield tempered glass when experiencing crashes [38]. The impact of the glass fracture stress was studied which can predict the acceleration level and cracks of the windshield glass.

Some researchers also focused on optimizing the manufacturing process and increasing the efficiency of handling automotive glass. Groom bridge et al. developed a visual feedback technology to improve the efficiency of handling automotive glass in the manufacturing process [39]. The technology tried to reduce the operator`s judgment and prevent mistakes by using artificial intelligence control systems which can predict and correct parameters during handling the curved automotive glass. This idea has now been widely used in automation line of automotive glass manufacturing.

2.3 Introduction of the current centering table

The schematic of the current representative centering table is shown in **Error! Reference source not found.**(A). This centering table consists of one base pad, three stands, one short-side column, two long-side columns, two air cylinders, and two columns of the air cylinder. The functions of all these components are discussed as follows: The base pad is used to support all the components for positioning. The base pad serves as the basis for the whole table. The stability of the base pad is very important for any operations on it. The stands constrain the motion of the glass to the horizontal direction, thus reducing the DOF of the glass. Three strands with equal height are used in the centering table to support the automotive glass and maintain the stability of the glass while positioning. The three stands with equal height are expected to prevent the motion of glass in the vertical direction. Air cylinders are fixed in the base pad and provide the power for the columns on the air cylinders and actuate the glass for positioning. The air cylinder and column on the air cylinder are used to push the glass moving towards to short-side column and long-side columns while maintaining the stable center of gravity of the glass. **Error! Reference source not found.**(B) shows the force analysis of the top view of the centering table with a gray circle illustrates the short-side column, long-side columns, and columns on the air cylinders. The yellow arrow shows the moving direction of the columns on air cylinders. Two air cylinders are adopted in the current centering table to maintain the rectilinear motion as one air cylinder cannot maintain the stable motion of glass. This can effectively prevent rotation or displacement of glass. Therefore, these two air cylinders were used to prevent the rotation of the glass during the motion process, increasing the degree of constraints and reducing the DOF of the glass. The short-side column serves as a barrier to stop and position the glass, which needs to bear the impact from the air cylinder.

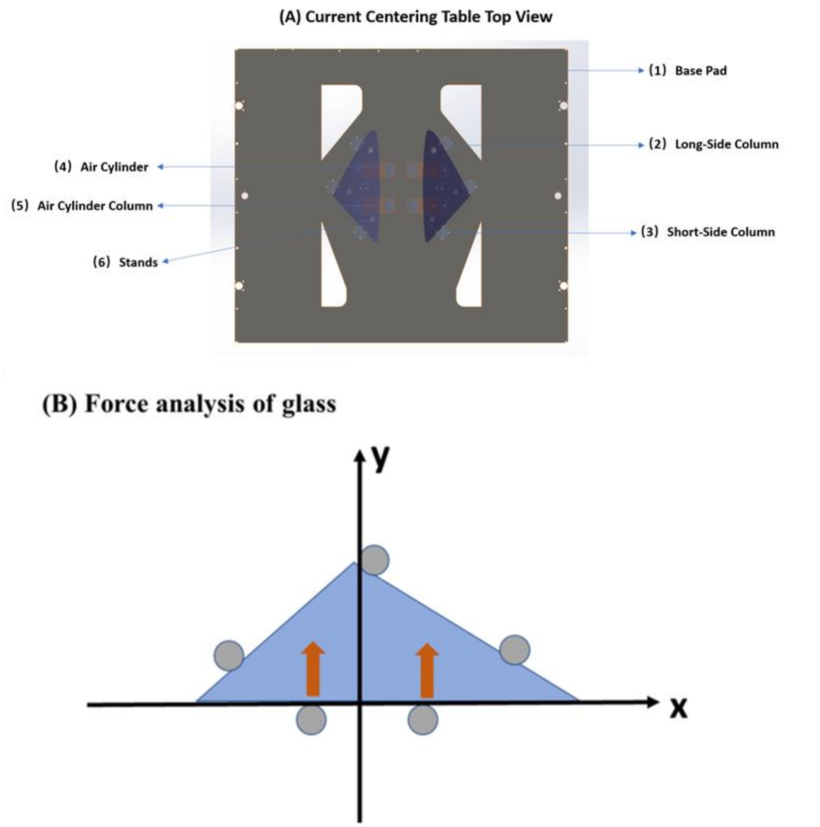

Figure 8(A) a schematic of the structure of the current centering table and (B) A schematic of the force analysis of glass on the centering table.

The structure used two long-side columns to prevent the glass rotating in the vertical direction. When the glass is actuated by the air cylinder and move in the y-axis, the force from the columns of the air cylinder will be compensated by the component force of the short-side column and long-side column in the y direction. The x axis component force of the short-side column will be compensated by the x axis component force of the two long-side columns. The two long-side columns can serve to maintain the glass on a preset position. This can also reduce the DOF of the glass in terms of rotary movement in the x-y plane. Therefore, the DOF of the glass is reduced to 0 in the current structure. The electronic components which are not shown in the schematic serve to receive and release signal, in order to connect the mechanical components with the central system. By the electronic components, the central system can control the actuation of the air cylinder and the positioning of the glass.

The working procedures of the centering table are as follows. (1) The robot hand on the automatic assembly line gripped the glass from the last fabricating process and placed it on the centering table. (2) The light sensing device (photosensitive sensor) on the base pad received the signal from the glass and transmitted it to the central controlling system. (3) Robot hand released the glass on the base pad after receiving the commands from the central controlling system. (4) The air cylinder started to extrude the glass one second after the robot hand withdrew. (5) When the glass was extruded to the set position, the magnetic sensors on the air cylinder returned a feedback to the central controlling system, after which the air cylinder started to withdraw. (6) After the air cylinder withdrew, the position of the glass was double-checked by repeating step (5). (7) The central controlling system commanded the robot hand to grip the glass after the air cylinder withdraws.

The structure of the column base on the centering table is shown in Figure 8. The columns are secured on the centering table with a round base. The detailed configuration of the base is shown in Figure 8. The Base is fastened on the centering table by the M4 screws. As shown in the right of Figure 8, the screw holes are in oval shape and wider than the M4 screws, which allows the M4 screws to be positioned in different locations. The dynamic area for the movement of the M4 screw is 1.5mm by 12 mm, as shown on the right of Figure 8. This means the columns can move in x axis with a range of 1.5 mm and move on the y axis with a range of 12 mm. This dynamic area actually ensures the flexibility of the center table. The pretightening force of the screw results in the force of friction, which can prevent the movement of the column along the horizontal direction. While the force of friction in this structure is not big enough to overcome the impact from the glass, which results in poor precision.

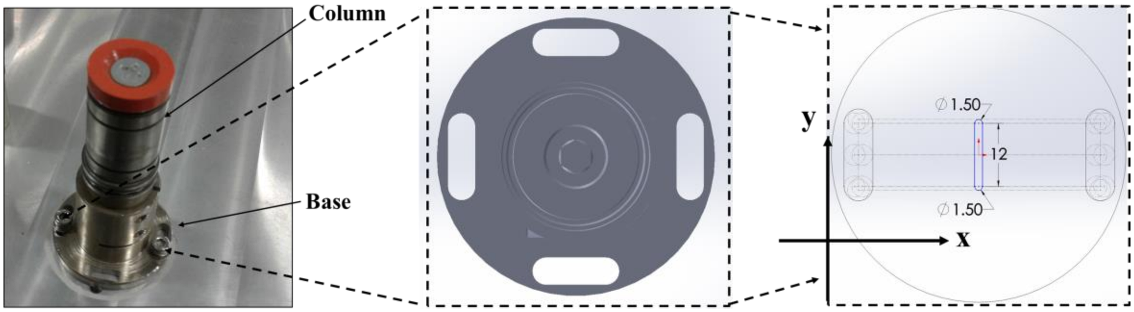

Figure 9 The structure of the column base on the current centering table.

2.4 Existing problems of the current centering table.

Though the current centering table has been applied for production in various places as it has some advantages. At first, the current centering table has a simple structure which can be easily configured and applied to mass production. This can reduce the cost of production. In addition, the components of this centering table can be easily replaced or adjusted. This provides convenience for error checking and mechanical repairing. Third, the columns on this structure can be easily adjusted into any directions. These advantages such as low cost and easy configuration made the center table very popular in many automotive glass fabrication companies. Therefore, the current centering table also is widely accepted for its cost-effective merits. However, the current structure still suffers from several disadvantages in the following aspects. (1) This centering table has poor versatility, it cannot be applied to glass with another configuration because of limited adjusting area. It can only be applied to specific glass shape, which means this structure can only produce a certain kind of automotive glass. Therefore, this poor versatility makes it expensive to produce other kinds of glass. (2) The precision in this structure is still poor. For example, there are some dislocations during this process. This results in low glass quality with some defects, as shown in Figure 10(A). Moreover, the deviation of the glass produced cannot meet the requirement of the allowable error, as shown in Figure 10(B). This poor precision will undoubtedly affect the following process and reduce the quality of production. （3）The adjusting parameter is not traceable. For example, operators set well the position of column base on one batch of parts. The column is dislocating when times fly by, at next time when the operators want to set the position back to original positions, they don't have any reference to find the correct positions (4) The program in this system also has a shortage. During the operating process, the columns on the air cylinder will retreat as long as they push the glass to the preset position. The glass can be rebound from the column after the columns on the air cylinder retreat as there is still momentum existing in the glass. If the robot grabs the glass right after glass is centered. This will result in dislocation of the glass, leading to poor precision and low fabrication quality. One method to solve this problem is to set the pause period when the columns on the air cylinder push the glass to the preset position. Based on some experiments, a pause period of 1 second is enough to remove any momentum on the glass and ensure that the glass maintains the preset position after positioned by the air cylinder. This means the columns on the air cylinder will stop for 1 second after pushing the glass to the preset position and then retreat.

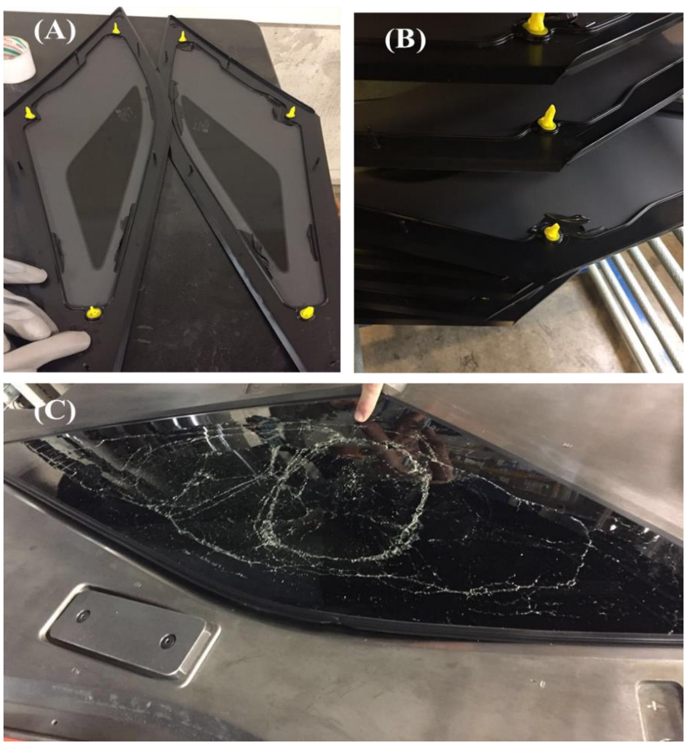

Figure 10 Low quality of the glass fabricated by the current centering table. (A) injection flash because of dislocation in the centering table, (B) large deviation, (C) chunk glass in the mold because of dislocation in the centering table.

2.5 Reasons accounted for the existing problems

1. Mechanical design problem.

It is the mechanical design problem that leads to the limitation of this current centering table. The current centering table used many fixed columns to reduce the degree of freedom in order to position the glass. However, the column with limited controlled area limited the application of this centering table to another glass with a different configuration such as different shapes or sizes.

2. Low fabrication precision of the bolts.

The bolts used to fix the columns are relatively small and cannot fix them tightly. The fabrication precision of the bolt is too low and there is a gap between the components after tightening the bolt. This results in dislocations and large deviation, leading to low quality of the glass.

3. The unstable constraints for the column in the horizontal direction.

The positioning column is only fixed by two bolts and the degree of freedom is restricted in the vertical direction, with poor constraints in the horizontal direction. In this case, even though the preloading force is large enough, the friction between the bolt and columns cannot exactly fix the glass in the horizontal direction as the force of percussion from the glass can be larger than the friction force, leading to displacement.

As we know, the poor positioning table will result in some serious problems in the products such as low quality of the products. Moreover, poor positioning table can affect the diagnosis when debugging problems, increasing the cost and time in production. Therefore, an excellent and precise centering table is necessary and indispensable for industrial production.

3 The analysis of finite element of this structure

3.1 The introduction to ABAQUS.

ABAQUS is a powerful software for finite element analysis. It can be applied to analyze complicated solid mechanics and structure mechanics because it is an excellent software for analyzing complicated models and processing nonlinear problems. ABAQUS includes abundant units and material models which enable itself to simulate any geometric structure and process most of the typical engineering materials, such as metals, hyperelastic materials, and polymers. ABAQUS mainly comprises of two modules: ABAQUS/Standard and ABAQUS/Explicit. ABAQUS/Standard is a more general module which can be applied to linear and nonlinear problems such as static state and dynamic state force and heat conduction. In the analysis of nonlinear problems, ABAQUS can automatically choose suitable load increment and convergence criterion. Furthermore, it can amend the parameters based on the calculation to ensure the precision of the results. ABAQUS/Explicit uses integral computation, which is suitable for analyzing transient dynamic events such as explosion and impact. It can maintain high precision and efficient when analyzing highly nonlinear problems such as contact process. In this paper, we adopted ABAQUS/Explicit to analyze the impact on the glass during the centering process. And we adopted ABAQUS/Standard to analyze the stress status of whole centering table during the pause time.

3.2 Finite element analysis model

We simplified the process of the impact of columns on the glass by only considering the components that involve in this process. The geometric model was simplified as Figure 11, which was applied to finite element analysis. The simplified geometric model consists four parts: (1) three columns on the left, which were considered as a rigid body for further analysis. (2) three supporting stands under the glass to support the glass. (3) Two air cylinders on the right, which have two columns on the top, these two columns impact the glass. (4) The tempered glass.

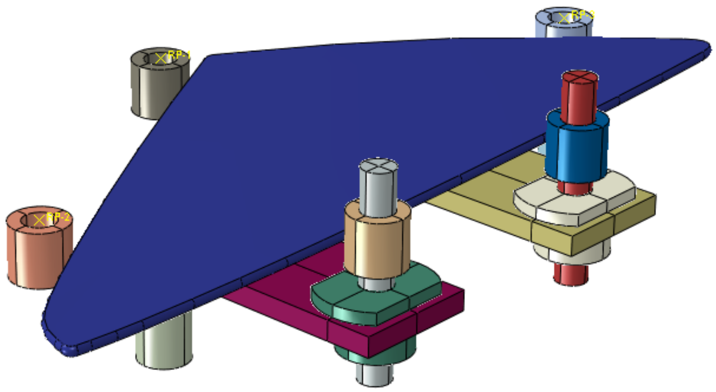

Figure 11 Simplified geometric model of the system.

The finite element analysis model was built based on this geometric model. All the materials except the tempered glass were considered as 304 stainless steel to simplify the analysis. The reported parameters of tempered glass are shown in Table 1.

Table 1 The reported parameters of tempered glass.

	Reported parameter
Density(Kg/m3)	2500
Young modulus (MPa)	73000
Poisson`s ratio	0.22
Ultimate strength (MPa)	300

Based on the above-simplified model, we can see that the three columns on the left and the three stands on the bottom of the glass are static and fixed. As the adopted column on the air cylinder has an impetus of 80N. The mass of the air cylinder is 2 kg and the moving distance of the column is 10 mm. Based on the acceleration process we can calculate the speed when the columns hit the glass is 1.2 m/s. The stress condition of the system is shown in Figure 12 (A).

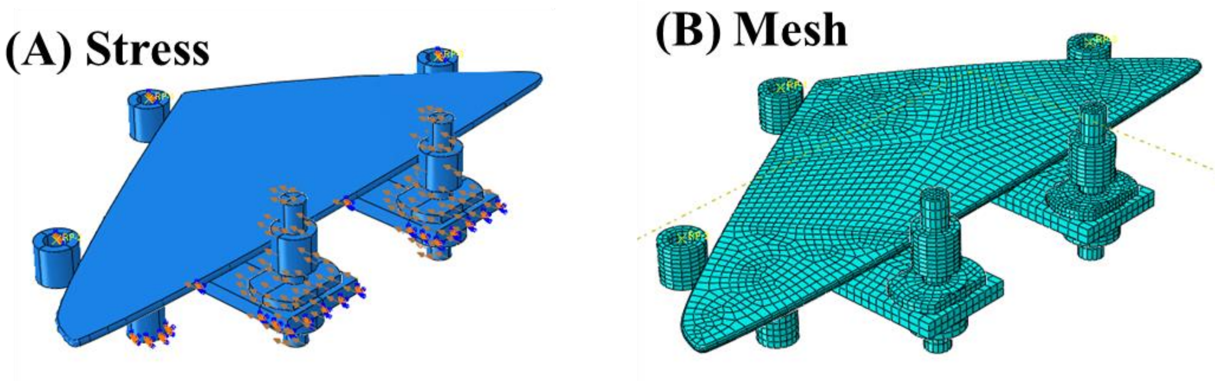

Figure 12 (A) The stress condition and (B) of the system based on finite element analysis.

The contact among different components was treated as a general contact. The C3D8R was adopted as the unit of this analysis [40]. We built a suitable mesh for the model to ensure the precision. The mesh contains 11767 grids and 16973 nodes, the meshed model is shown in Figure 12(B).

3.3 Results of finite element analysis.

Based on the ABAQUS simulation, we got the maximum stress distribution at different times. The maximum stress distribution can be used as the criterion to evaluate the strength of the glass because tempered glass has brittleness. The maximum stress distribution at different times is shown in Figure 13(A) to (H), from which we can see the variation of the maximum stress of the glass during the impact process. At 0s, the stress distribution is zero (as shown in Figure 13(A)).

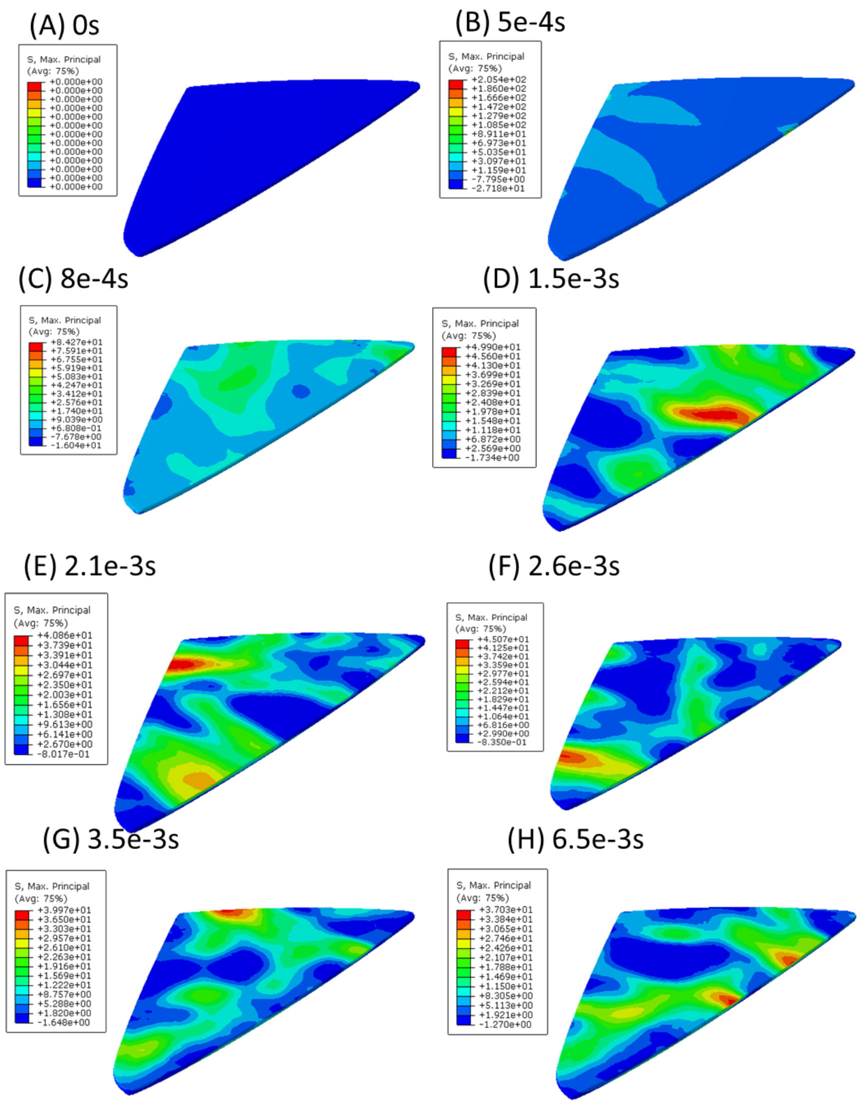

Figure 13 The maximum stress distribution of the glass at different times.

After the impact from the columns, the stress on the area near the columns increases rapidly. For an impact from the air cylinder with an impetus of 80N, the speed of the column before impact is 1.2 m/s. The maximum stress on the glass during the impact process can achieve 205 MPa. The relationship of variation of the stress on tempered glass and time is shown in Figure 14. From Figure 14, the stress increases to a maximum value rapidly at the beginning the glass was impacted by the columns and then decreases rapidly. Then the stress wave maintained fluctuating with a small amplitude.

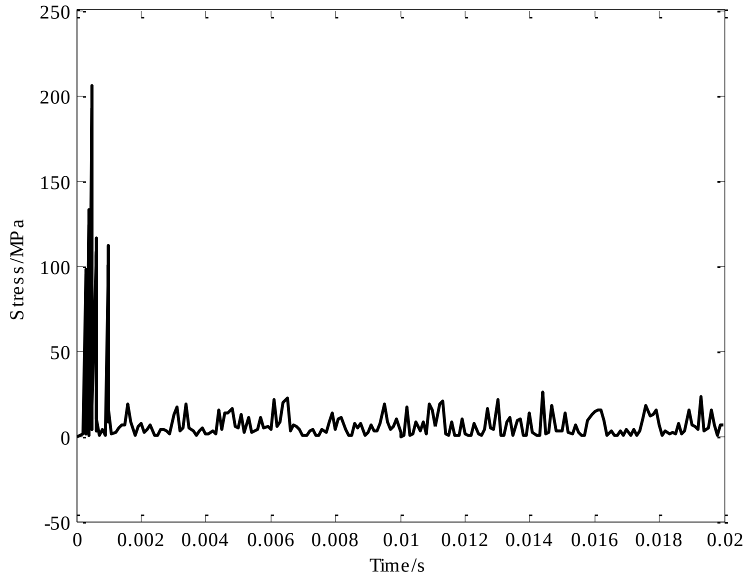

Figure 14 The variation of stress on the glass vs. time.

From the finite element analysis, we can also get the variation of reactive force on the three fixed columns at different times. The locations of the three fixed columns are shown in Figure 15, which shows the bottom view of the centering system. The corresponding reactive force variation with times are shown in Figure 15 (B), (C) and (D).

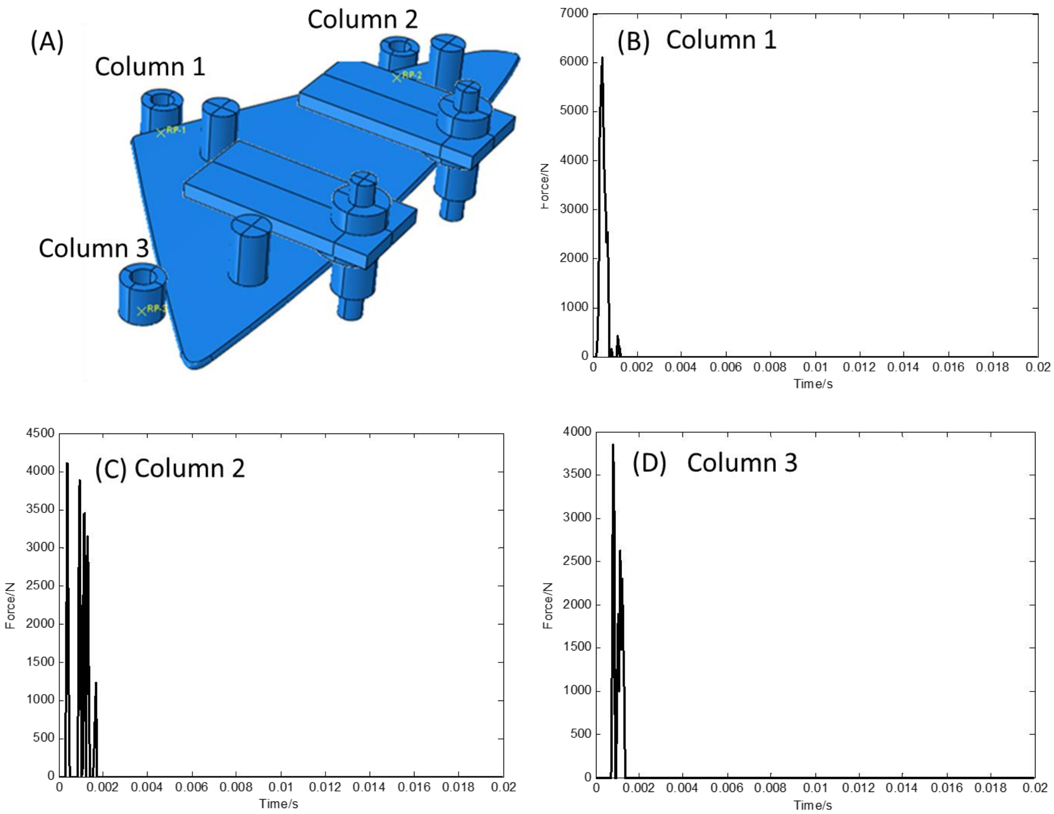

Figure 15 (A) The bottom view of the centering system shows the locations of the three fixed columns. (B), (C), and (D) illustrate the variation of force on column 1, column 2, and column 3, respectively.

In order to investigate the stress variation under different impetus from the air cylinders, we simulate the impetus (output force) of the air cylinder ranging from 40 to 160 N with 10 N increment. The stress variation of the glass under different impetus from the air cylinders is illustrated in Figure 16. Figure 16 shows that with the impetus increasing, the stress of tempered stress increases. When the impetus exceeds 150N, the stress increases rapidly. Under an impetus of 150N, the stress on the tempered glass reaches 302MPa, while the ultimate strength of the tempered glass is 300MPa. This means the tempered glass fractures when the impetus of the air cylinder exceeds 150N.

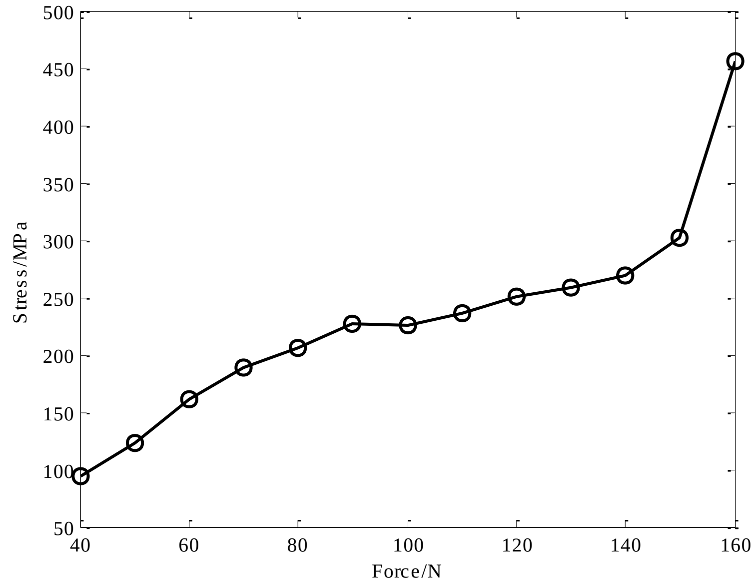

Figure 16 The stress variation of the glass under different impetus from the air cylinders.

These three columns rely on the force of friction between the column base and the base pad to constrain the DOF on the horizontal plane, which means the impetus from the glass on the columns should not be larger than the force of friction. If the impact on the columns is larger than the force of friction, there would be dislocation of the glass. The pretightening force for the M4 bolts is 948 N and the coefficient of friction on the M4 bolts for glass is usually smaller than 0.1. Therefore, a suitable impetus from the air cylinder will be smaller than 100N. From the Figure 14, we found the forces on column 1, 2 and 3 are much higher than the friction force between column and plate base. This is the reason why the columns always are dislocated. Under pause time, we adopted 80N as the impetus of the air cylinder and analyze the stress of the tempered glass on the static state. Figure.16 shows the finite element analysis of the stress distribution on the glass on static state (which the glass is impacted by the columns). Based on the finite element analysis, we can get the maximum stress point is only 5.27MPa, which is much lower than the ultimate strength. The reactive force on column 1, column 2, and column 3 is 62.3N, 71.1N, and 60.3N, respectively.

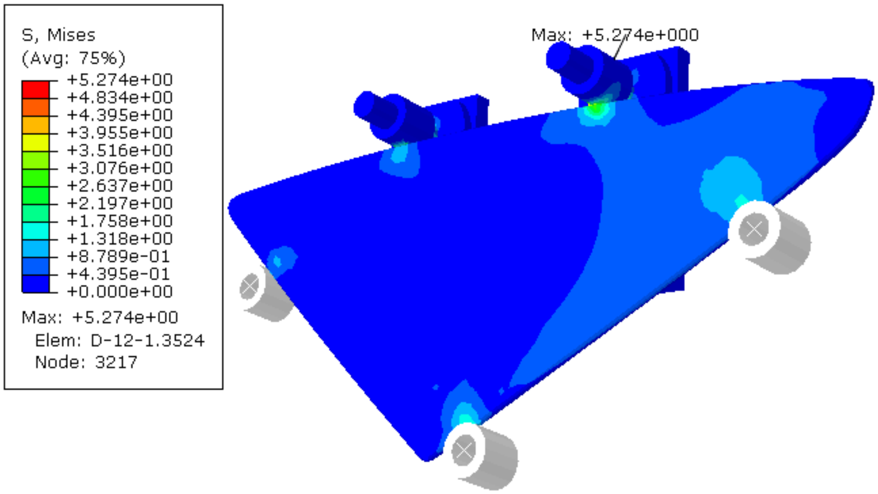

Figure 17 The stress distribution on the glass on static state with an impetus of 80N.

Figure 18 shows the force analysis of the glass on the centering table. The relative position of the glass and the columns are shown in Figure 18(A). The gray circles represent the columns on air cylinders, short-side columns, and long-side columns. The blue triangle shape represents the glass sample. Simplified stress analysis model was carried out, the glass can be treated as a mass point that is subject to the force from the air cylinders (F_1), the force from the long-side column (F_2), and force from the short-side column (F_3), as shown in Figure 18(B). Base on the glass sample placed on the centering table, we can measure the angles of the blue triangle as 108°, 30°, and 42°, which means the included angle between F_2 and horizontal direction (x axis) is 60° and the included angle between F_3 and horizontal direction (x axis) is 48°. Therefore, the component force of F_2 in the horizontal direction (x axis) is $F_2\cos60$, the component force of F_2 in the vertical direction (y axis) is $F_2\sin60$. The component force of F_3 in the horizontal direction (x axis) is $F_3\cos48^\circ$, the component force of F_3 in the vertical direction (y axis) is $F_3\sin48^\circ$. Based on the finite element analysis of the static moment of the glass [41], we have:

$$F_2\cos60^\circ = F_3\cos48^\circ,$$

$$F_1 = F_2 \sin 60^{\circ} + F_3 \sin 48^{\circ}.$$

As $\sin 60^{\circ} = 0.86$, $\sin 48^{\circ} = 0.74$, $\cos 60^{\circ} = 0.5$, $\cos 48^{\circ} = 0.66$. The output force of the air cylinder is 80 N because there is two air cylinders serve as the force source for the glass, then F_1=160 N, so the above equation can be simplified as：

$$0.5\, F_2 = 0.66\, F_3,$$

$$0.86\, F_2 + 0.74\, F_3 = 160\text{N},$$

Therefore. F_3=85.3 N, F_2= 112.6 N. The output of the air cylinder is half of the F_2. There is some deviation between the finite element analysis and the theoretical analysis. This might be due to the smoothness of the glass surface; the curvature may be different from the estimating value. Base on the result of the static analysis, it shows the columns 1, 2, and 3 maintain under a safe condition during the pause time.

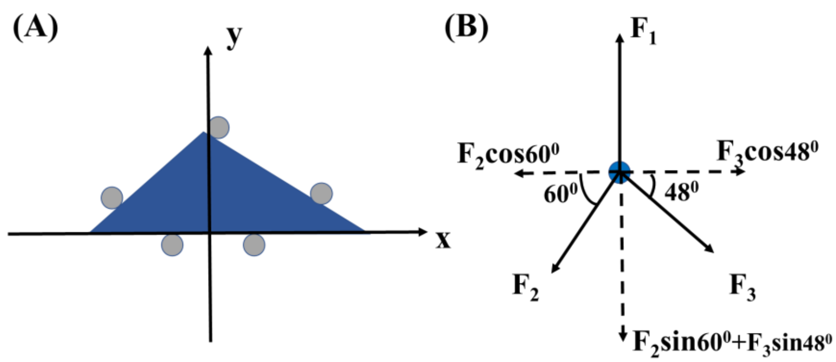

Figure 18 (A) The relative position of the glass and the columns. (B) The force analysis of the glass under the pressure of columns on the centering table.

4 New design of the centering table

As the developing industry required an automatic assembly line with the high quality, high efficiency, and high precision to meet the increasingly high demand of the market. While High-quality requirement usually results in a more complicated procedure and more time, which increases the cost of fabrication. The requirement of the fabrication is increasing for the complicated glass shapes and inserted functional and aesthetic details of the glass. This requires additional process and effort, leading to higher labor force cost. Considering the vast demand for the automotive glass, the efficiency of fabrication needs to be boosted. However, as the current centering table suffering from many disadvantages such as poor versatility, poor precision, and low efficiency. Therefore, new technologies need to be developed and adopted to meet increasing demand of the market, reduce manufacturing cost, and maintain a high quality of the quarter window glass.

4.1 The design and working principle of air cylinder

4.1.1 Introduction of air cylinders

Air cylinder, also called pneumatic cylinder, serves as a power source that provides a force for the movement of the components in a reciprocating linear movement. Air cylinders are widely adopted in industry as they are environmental-friendly, space-saving, and quiet. The structure of an air cylinder is usually chosen and optimized by selecting proper components such as suitable bore size, proper stopping mechanism, and good configuration. An air cylinder uses the power of compressed air that can generate pressure or force on the piston, facilitating a reciprocating linear motion [42]. A general air cylinder consists of the cylinder body, obturating ring, cylinder rod, magnetic ring, piston etc., as shown in Figure 19. The working principle of a general air cylinder is as follows: the compressed air forced the piston to move, the movement of the piston would change the direction of the air flow, leading to change of moving direction of the cylinder rod. As we can see from Figure 19, the operation of the air cylinder depended on all the statuses of all the components. Any malfunctioning component will result in malfunction of the air cylinder. The general failures of an air cylinder include powerless cylinder rod, piston sticking, obturating ring abrasion, and air leakage.

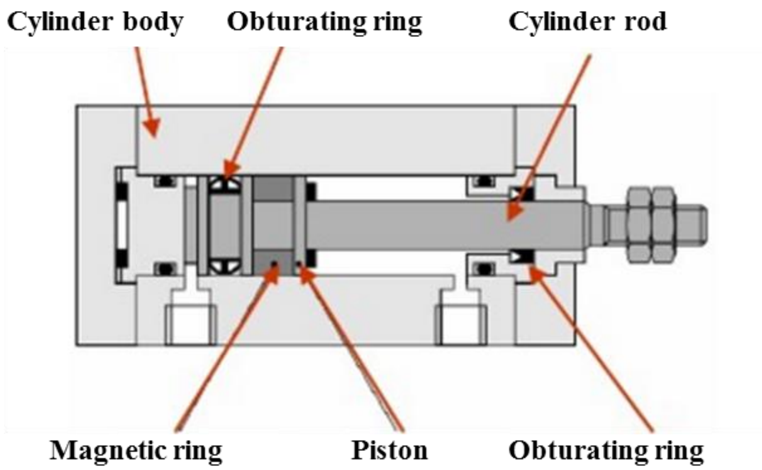

Figure 19 The structure and components of the traditional air cylinder.

4.1.2 The air cylinder adopted in our centering table

In our research, the model of the air cylinder that we chose is SMC A_MXS12-30-A90, which refers to the series MXS, with bore size (stroke) of 30 mm, adjuster on both ends (adjustable stroke range 0 to 5 mm), buffer mechanism, and centralized piping in the axial direction. The picture of the adopted SMC A_MXS12 air cylinder is shown in Figure 20(A). The parameters of overhand in the adopted air cylinder are illustrated in Figure 20(B). Three different overhand sizes are expressed as L_1, L_2, and L_3, as illustrated in Figure 20(B). The detailed parameters regarding the configuration of the air cylinder are shown in Figure 20(C). The parameters of the selected air cylinder are summarized in Table 2 [43].

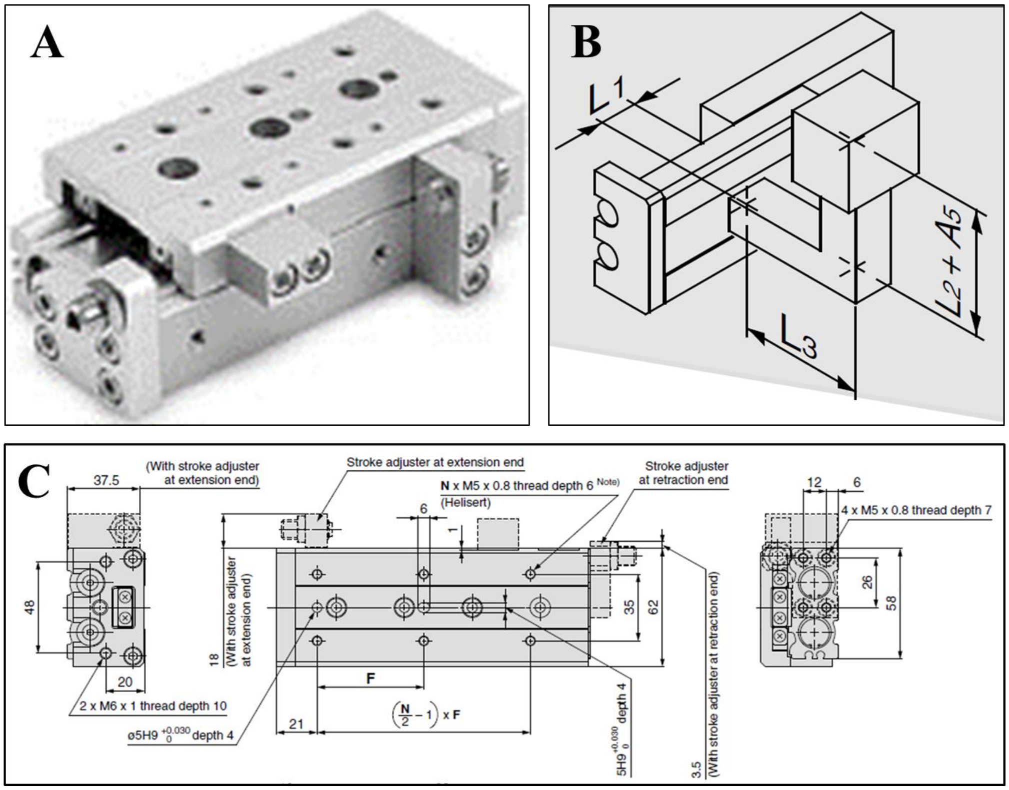

Figure 20 (A) The picture of the adopted SMC A_MXS12 air cylinder, (B) The parameter of overhand in the adopted air cylinder. (C) The detailed parameters regarding the configuration of the air cylinder.

Table 2 Detailed parameters of the selected air cylinder.

Cylinder model	Mounting	Average speed Va(mm/s)	Load mass(W: kg)	Overhang (mm)		
MXS12-30	Horizontal wall mounting	300	0.2	L1	L2	L3
				20	0	30

4.1.3 Output of the selected air cylinder

The output force of the air cylinder is not only depended on the size of the air cylinder but also depended on the operating pressure. The dual rod structure in the selected air cylinder makes the output force twice the single rod air cylinder. From Figure 15, we know that the impetus of the air cylinder should not be higher than 150N. Table 3 shows the detailed parameters of the air cylinder and the output force. The selected module is SMC A_MXS12 and the related parameter is highlighted in red, as shown in Table 3. The output of the selected air cylinder can effectively prevent the output exceeding 150 N even though the operator makes some mistakes in adjusting the operating pressure. As the operating pressure of the selected air cylinder is 0.2 MPa, the output force is 45N。

Table 3 The operating pressure and output force of the SMC series air cylinders.

Theoretical Output

OUT ← → IN

The dual rod ensures an output twice that of existing cylinders. (N)

Bore size (mm)	Rod size (mm)	Operating direction	Piston area (mm²)	Operating pressure (MPa)					
				0.2	0.3	0.4	0.5	0.6	0.7
6	3	OUT	57	11	17	23	29	34	40
		IN	42	8	13	17	21	25	29
8	4	OUT	101	20	30	40	51	61	71
		IN	75	15	23	30	38	45	53
12	6	OUT	226	45	68	90	113	136	158
		IN	170	34	51	68	85	102	119
16	8	OUT	402	80	121	161	201	241	281
		IN	302	60	91	121	151	181	211
20	10	OUT	628	126	188	251	314	377	440
		IN	471	94	141	188	236	283	330
25	12	OUT	982	196	295	393	491	589	687
		IN	756	151	227	302	378	454	529

Note) Theoretical output (N) = Pressure (MPa) x Piston area (mm²)

The model provides many advantages such as precision, cost-effectiveness, stability. The model of air cylinder was chosen for the following reasons. (1) This model improves the mounting repeatability of the workpiece, which increases the flexibility of the system and ensures the stability of the extrusion. (2) The model can provide an adjustable stroke range of 5 mm, which improves the compatibility of the air cylinder. (3) The buffer mechanism in the air cylinder will protect workpieces and eliminate the impact of force during extension. Moreover, this buffer unit can provide an automatic switch. (4) The piping type of this air cylinder centralizes piping in the axial direction to keep clear space around the cylinder. The dual piston rod ensures twice the trust of the current cylinder. (5) The load factors of this structure are estimated to be

0.25, which meets the requirement of the allowable load factors.（6）This the structure has adjusted at both ends, which provide good flexibility and can be easily configured.

4.2 The introduction of pins

A pin is an important tool in the mechanism that serves to secure the position of two components of the system. Especially in some workpiece with a rough surface or non-right angle, pins can be used to secure their relative position [44]. The working principle of an alignment pin is to increase the degree of constraint and reduce the degree of freedom. Figure 21 shows the schematic of a short alignment pin and a long alignment pin. For example, a short position pin can reduce two degrees of freedom and a long position pin can reduce four degrees of freedom, while taper pin can reduce three degrees of freedom. Comparing with bolts, alignment pins have a higher working accuracy as pins have a very smaller gap that is much smaller than the gap exists between a bolt and a hole, resulting in a higher precision. Moreover, the working accuracy of pins is much higher than bolts, which means the size or shape defined by the pins is more accurate. Furthermore, the contact between a pin and a pin hole is surface contact. The big contact surface ensures the tightness of the structure [44]. Therefore, in the center table, pins are preferred than bolts.

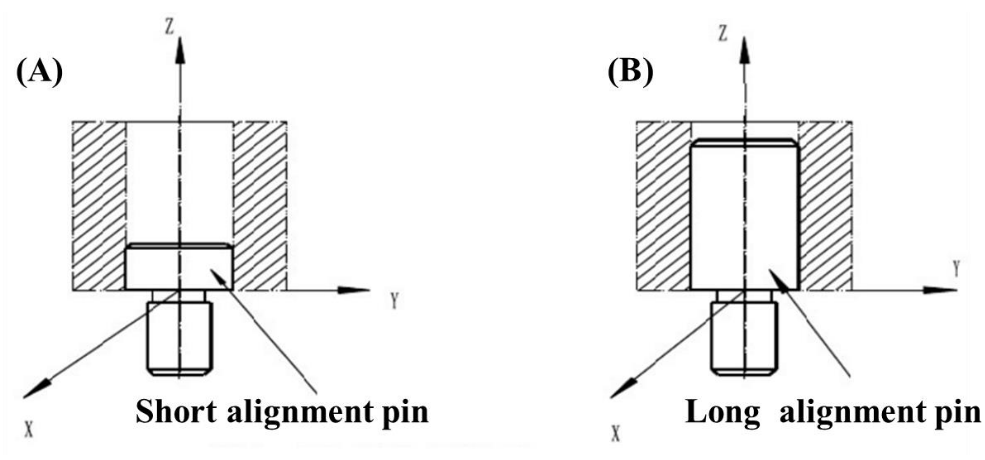

Figure 21 the schematic of (A) a short alignment pin and (B) a long alignment pin.

4.3 The new design of the column base.

Based on the discussion above, we tried to develop a new design of the column base that takes advantage of pins for tightening the column base on the centering table. This can make sure the tightness of the column, ensuring the precision and stabilization during the positioning process. However, in the new design, two adopting pins as tightening tool reduces the DOF of column base to one, which means the columns cannot be moved in any direction except the vertical direction. And two M12 bolts could restrict its flexibility to different glass sizes. Therefore, we divided the vertical DOF of column base. In order to make the column base more flexible for different glass size, we insert shims with a different width to adjust the position of the columns, as shown in Figure 22. The new design of the column base consists of M10 bolts to tighten the components after assembling the columns, shims with different widths to adjust the distance between the two components, M12 bolts to fix column base on the table, and pin holes in which pins can be inserted to tighten the column base with stable position on the centering table.

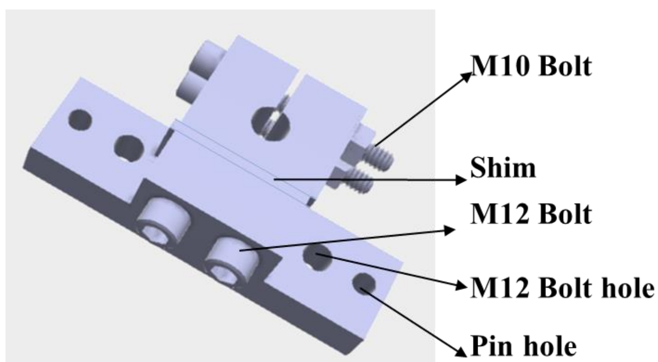

Figure 22 The structure of the new design of the column base.

Figure 23 shows the schematic of the column base after assembling the column. The column base is mounted on the station by dowel pins and bolts, resulting in a much more stable base. The M12 bolts are used for rough positioning of the column base and the pins are used to exactly tighten the column base on the centering table. In this new design, the positioning column on the column base is made adjustable to make the centering table compatible with other kinds of glass with different configurations. The adjustability of the new centering table is achieved by putting in and taking out shims with different thickness by which the distance of the two components of the column base can be changed. The shims for one station consist of different kinds of shims. The thickness of shim is 5mm which consists of two 0.25mm thickness shims, three 0.5 thickness shims, one 1mm thickness shim, and one 2mm-thickness shim. One of the drawbacks in this new design is that all the column bases should be adjusted when the system is changed to cater to different glass configuration. This means all the shims on the three column bases should be changed when we want to apply this centering table to position a glass sample with different size. As we know, flexibility and tightness are a tradeoff. It is difficult to achieve high flexibility and maintaining the tightness of the columns. Usually, a system with high flexibility which can be easily adjusted to meet different needs cannot guarantee the tightness and precision of the operation. For the industrial requirement, precision is usually a more important parameter, which is directly related to quality. Therefore, as long as we can achieve the flexibility to meet the needs of the industry, emphasizing on the tightness and precision of the system should be encouraged.

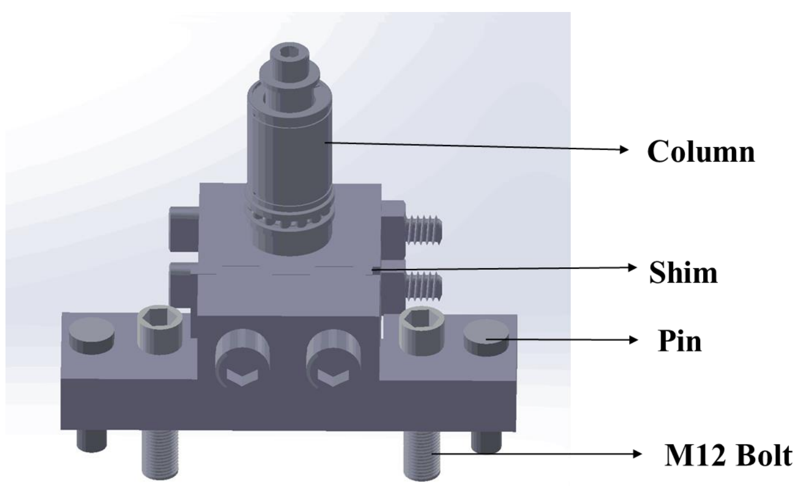

Figure 23 The schematic of the column base after assembling the column.

4.4 The new design of the centering table.

The new design of the centering table which contains six position stations is shown in Figure 24. The base pad was fixed by bolts to maintain a stable centering table. Six positioning column bases were arranged to accommodate general shape and size of the glass of the quarter window. By adopting the adjustable positioning columns, this centering table can be used to different sizes and shapes of quarter window glass. For total 6 position stations (base of positioning), the quantity of 0.25 mm thickness shims is 12, the quantity of 0.5mm thickness shims is 18, the 1mm thickness shims are 6, and the quantity of 2mm thickness shim is 6.

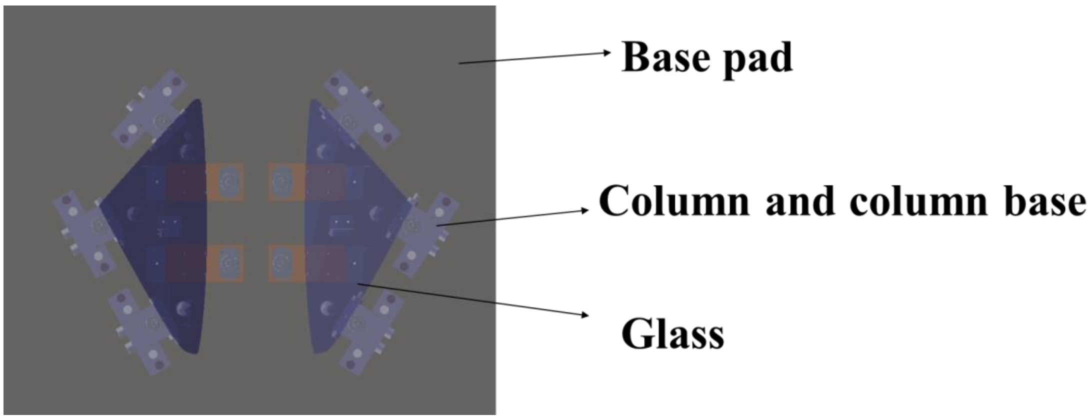

Figure 24 The new design of the centering table which contains six columns.

4.5 Verification test of the new design

4.5.1 Fabricating result using the new centering table

After accomplishing the new design of the column base and the centering table. We fabricated all the designed components in the factory and assembled all the components into a new centering table. Moreover, this new center table was also applied to real fabrication. We used this new centering table to fabrication a lot of glass for quarter windows. In this section, the pictures of the fabricated glass using the new centering table will be covered. In addition, the section will include the statistical data of the glass fabricated using the previous centering table and the newly designed centering table.

An assembly line that adopted for fabricating the new glass is a general assembly line with a new centering station (a new centering table) which includes glass priming station, glass centering station, glass loading robot, injection machine, and post processing robot etc. The centering and positioning processes of the new centering table are as follows: (1) A robot hand grips the glass from the last fabricating process and places it on the centering table. (2) The light sensing device (photosensitive sensor) on the base pad receives the signal from the glass and transmits it to the central controlling system. (3) Robot hand releases the glass on the base pad of the new centering table after receiving the commands from the central controlling system. (4) The air cylinder starts to extrude the glass one second after the robot hand withdraws. (5) When the glass was extruded to the preset position, the magnetic sensors on the air cylinder returned a feedback to the central controlling system, after which the air cylinder starts to withdraw. (6) After the air cylinder withdraws, the position of the glass is double-checked by repeating step (5). (7) The central controlling system commands the robot hand to grip the glass before the air cylinder withdraws. The picture of the newly centering table is shown in Figure 25.

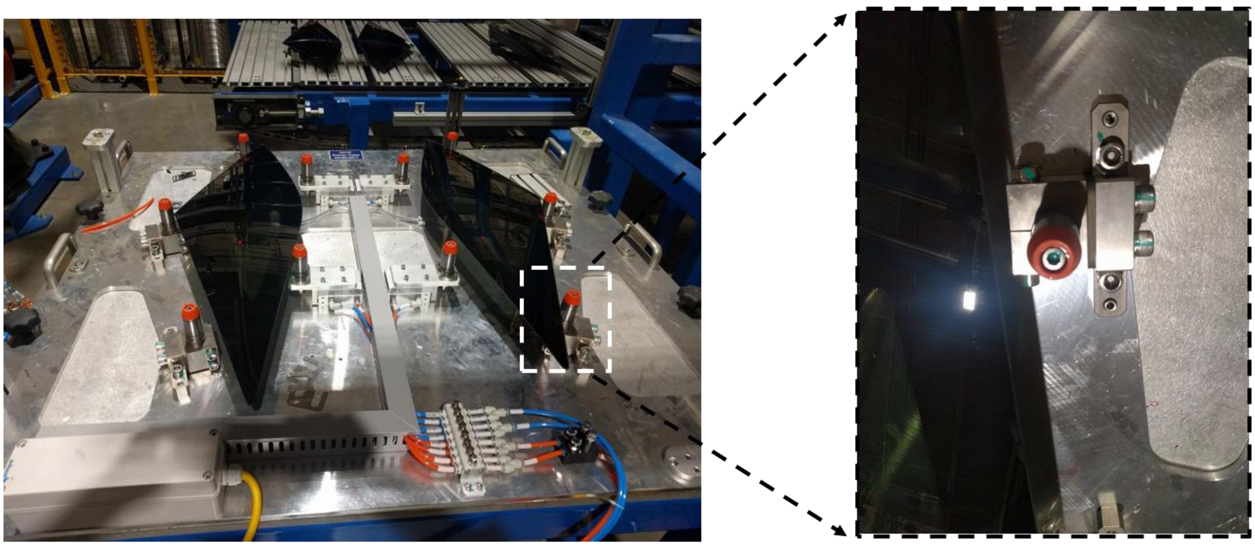

Figure 25 The picture of the newly centering table.

4.5.2 Comparison data of glass fabricated using the previous centering table and the new centering table.

By designing the new centering table, we aim to realize efficient and cost-effective fabrication of automotive glass. In order to test the efficiency of the new design of the centering table, we carried out comparison testing. The experiment was carried out in Lake Orion facility. We assumed that the numbers of automotive glass fabricated every day are the same and we can exactly recognize the reason for the unqualified automotive glass. The automotive glass is operated using the previous centering table and the new centering table. The positions of columns were adjusted to fit the specific automotive glass before the experiment. This can match with the theoretical analysis. All the equipment on the assembly line was operated properly. The numbers of unqualified automotive glass were documented every day and summarized in Table 4.

From Table 4, we can see that the automotive glass operated by the old centering table had a higher failure rate than the ones operated by the new centering table. Except for the second day, both the number of damaged automotive glass and the number of dislocated automotive glass operated by the old centering table is higher than that operated by the new centering table. In addition, the failure rate of the automotive glass operated by the old centering table was increasing from day 1 to day 6. This is due to the accumulation of displacement. The loss of precision can be accumulated and leads to a high failure rate of automotive glass. Furthermore, the old centering table was adjusted due to the high rate of failure and the data was not collected to prevent other factors affecting the result of the comparison.

Table 4 The comparison data of glass fabricated using the previous centering table and the new centering table.

Table	**Reason of failure**	**Number of failure in different days**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Old table	**damaged**	**1**	**0**	**2**	**2**	**5**	**8**	**Centering Table was adjusted due to the high rate of failure**		
	dislocated	**0**	**1**	**2**	**4**	**6**	**10**			
New table	**damaged**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**
	dislocated	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**2**

4.5.3 CMM testing on the as-fabricated glass using new centering table.

In order to explore the precision of the new centering table, we carried out geometrical testing on the fabricated automotive glass by the coordinate measuring machine (CMM). The CMM can define the geometry of the fabricated automotive glass by attaching the probe to the moving axis. Usually, all the data in different perspectives of the object can be measured and read by the CMM. The CMM measures the object in six degrees of freedom and shows all the data in the mathematical form. For the experiment, we randomly selected 10 pieces of automotive glass and assume that all the automotive glass can meet the requirement of the industrial production and could be processed in the following procedure. We assumed that the sizes of all the raw glass did not change with time and temperature. In addition, we assume that the robot hand and other injection equipment will not affect the size of glass during the experiment. The detailed method of the experiment is as follows: (1) randomly select 10 pieces of glass without any priming process. This can facilitate the process of disassembly. (2) place all the 10 pieces of glass on the centering table respectively and use the table to position the glass. (3) After the centering table position the glass, the robot hand gripped the prepositioned glass and placed on the injection machine. (3) the injection machine injected the PVC and form the encapsulated automotive glass. (4) the encapsulated glass was gripped and put into the CMM to measure the size of the glass. After the CMM measurement, the PVC on the encapsulated glass will be removed for the test of the next step. The CMM test results in Table 5 shows that the glass fabricated by the new centering table has a higher pass rate, especially after a period of time (such as operating for 5 days) while the glass fabricated by the old centering table has a much lower pass rate in the Day 5. This means the structure designed has a higher precision for industrial production. Figure 26 shows A picture of the CMM Machine Room.

Table 5 CMM testing data of 10 pieces of glass by the previous table and the new table.

Table	Glass Fabricated on Different Days	Measurement of 10 pieces of glass(Pass or not)										Pass Rate
		1	2	3	4	5	6	7	8	9	10	
Old Table	Day 1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	100%
	Day 5	Fail	Pass	Fail	Fail	Fail	Fail	Pass	Fail	Pass	Fail	30%
New Table	Day 1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	100%
	Day 5	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	90%

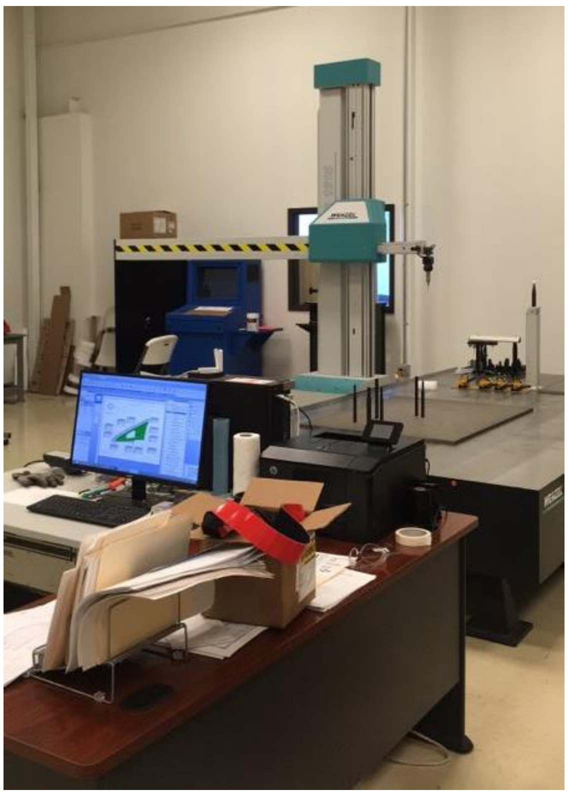

Figure 26 A picture of the CMM Machine Room.

4.6 Advantages and disadvantages of the new centering table

The first advantage of the new centering table is the stability and precision. The new design adopted pins for tightening. Pins work much better than bolts for tightening. The precision of the bolt is too low (at approximately 5 mm) and there is a gap between the components after tightening the bolt. This results in dislocations and large deviation, leading to low quality of the glass. While pins use surface contact which is much stable and tight. The second advantage of this new centering table is the accurate adjustability of the column base. By adding and removing shims with different widths, the positions of columns can be adjusted, so as the position of the glass. This can be applied to glass with different sizes and shapes. One of the drawbacks of this new design is that all the column bases should be adjusted when the system is changed to cater a different glass configuration. This means all the shims on the three column bases should be changed when we want to apply this centering table to position a glass sample with different size. As we know, flexibility and tightness are a tradeoff. It is difficult to achieve high flexibility and maintaining the tightness of the columns. Usually, a system with high flexibility which can be easily adjusted to meet different needs cannot guarantee the tightness and precision of the operation. For the industrial requirement, precision is usually a more important parameter, which is directly related to quality. Therefore, as long as we can achieve the flexibility to meet the needs of the industry, emphasizing on the tightness and precision of the system should be encouraged.

5 Conclusion

With the development of industry and the increasingly high requirement for mechanical products, the operating efficiency, and precision of centering table for the fabrication of encapsulated automotive glass become very important in the industry. The previous centering table fails to guarantee the precision and quality of the product, which cannot meet the needs of the current industry. This thesis focused on developing a new centering table with high stability and precision for encapsulated glass positioning. To sum up, the thesis included the following points:

(1) As the automotive quarter window is in a triangle shape, the presented positioning structure with three stands, three columns, and two air cylinders can effectively position the quarter window glass.

(2) Tightening by screw fails to provide good precision and stability as the force of friction on the columns cannot overcome the impact from the quarter window glass.

(3) Based on the finite element analysis, the impetus from the air cylinder should not exceed 150N, which can result in fracture of tempered glass. The simulation result is consistent with the theoretical analysis.

(4) Pins are much easier to be fabricated and have much higher precision and stability, which make them suitable for positioning. The new centering table adopted pins to fix the columns and the column base, which realizes high precision. In addition, the new centering table can effectively reduce the DOF of the quarter window glass.

(5) The newly designed column based has better adjustability and stability, which can guarantee the precision of production. By changing the shims on the column base, the new centering table can be used for quarter window glass with different sizes.

(6) CMM measurement was carried out and the experimental data verified the productivity and the precision of the new centering table.

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ABSTRACT

A NEW CENTERING TABLE FOR ENCAPSULATED GLASS POSITIONING

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With the progress of the society, people`s living standard is increasing. More and more cars (more than 72 million) are produced and utilized all over the world. This makes a large number of quarter windows which located on the back-side window of a vehicle are urgently needed. Encapsulated glass is widely adopted for a quarter window for various advantages. Positioning by centering table is one of the most important procedures during the fabrication of encapsulated glass for the quarter window. The existing centering table has a lot of disadvantages such as poor flexibility and precision, which results in failure in production such as damage or low quality. Developing a centering system for positioning encapsulated glass with high efficiency and precision becomes very significant for the industry. In this thesis, I designed a new centering table that used a new column base structure and pins for tightness. This new centering table has a high precision while still maintain the flexibility of the table that makes the centering table can be applied to encapsulated automotive glass with other sizes and shapes.